Stocking Rate and Dairy Production in New Zealand: An Analysis of the UQR Model with Fixed Effects

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Abstract

This paper analyzes the effects of stocking rate on dairy production, using New Zealand dairy farm business data for the period 2005-2014. Unlike previous studies that assume a homogenous relationship between stocking rate and dairy production, we contribute to the literature by investigating the heterogeneous effects of stocking rate on milksolids production and applying an unconditional quantile regression model with fixed effects to control for unobserved farm-specific traits that are time invariant. The empirical results show that stocking rate exerts significant heterogeneous effects on milksolids production at different quantiles. In particular, we find that an additional increase in stocking rate (i.e. one cow/ha increase) increases milksolids production per hectare by 0.18%~0.25% but decreases milksolids production per cow by 0.05%~0.12%. In addition, we find that milking interval, dairy breed, farm labour, access to irrigation and farm location are important factors that increase milksolids production.

Keywords: Stocking rate; Milksolids production; Unconditional quantile regression; Fixed effects; New Zealand

JEL Codes: C32; D13; D22

1. Introduction

In response to price and other signals, dairy farmers have a range of available options to increase production. A typical option is to increase farm size, however, the rising cost and reduced availability of land suitable for dairy farming has meant that this option is increasingly limited or even non-existent (Fariña et al. 2011). An alternative approach is to intensify production on the existing farm area which generally involves either increasing yield per cow and/or the number of cows per hectare (i.e. stocking rate). Among a range of interrelated factors (e.g., stocking rate, calving date, nitrogen fertilisation and concentrate feed supplementation) that affect dairy productivity in pasture-based systems, stocking rate has widely been accepted as the most important factor determining milk output (McCarthy et al. 2010; Monaghan et al. 2005; Macdonald et al. 2008; Fariña et al. 2011).[1] In essence, appropriate dairy farm management that involves correctly aligning the stocking rate to the seasonal supply of pasture and herd intake demand facilitates pasture and supplementary feed utilization and improves farm economic performance. Increasing stocking rate can though bring environmental and animal welfare challenges (Spaans et al. 2018; Herzog, Winckler, and Zollitsch 2018), so it is important that when considering possible trade-offs that a clear understanding of its impact on production and profitability is attained.

Several studies have analysed the relationship between stocking rate and dairy production based on descriptive analysis of production data and/or different stocking rate experiments (Macdonald et al. 2011; Fariña et al. 2011; Fike et al. 2003; Baudracco et al. 2011; Patton, Pierce, and Horan 2016). Generally, they demonstrated that higher stocking rates contribute to an increase in milk production per hectare, but a decrease in milk production per cow. For example, Macdonald et al. (2008) found in New Zealand that with increasing stocking rate, milk production per hectare increased but there was a linear decline in production per cow. In

[1] Stocking rate is generally defined as the number of milking cows per unit of effective land area (cows/hectare).

their meta-analysis, McCarthy et al. (2010) showed that an additional increase in stocking rate increases milk yield per hectare by 19.6 to 20.1%, but decreases daily milk yield per cow by 7.4 to 8.7%. In an experimental study carried out in the Republic of Ireland between 2008 and 2011, Patton et al. (2016) revealed that increased stocking rate on the grazing platform increased milk production per hectare. On one hand, a high stocking rate enables increased forage and supplement intake during lactation, especially when pasture growth is vigorous, and therefore less pasture is wasted due to trampling, fouling and rejection. On the other hand, if supplementary feed does not compensate for the reduction in pasture allowance, individual cow intake of pasture decreases as stocking rate increases, reducing milk yield per cow.

Stocking rate might affect dairy farms differently, given the possibility of different levels of productivity among farms. However, the existing literature relies on average estimates of stocking rate, which fails to disentangle the effects of stocking rate across different levels of dairy production. Knowledge of the relationship between stocking rate across the entire distribution of dairy production is fundamental to the sustainable management of intensified grazing systems, and can provide dairy industry stakeholders with information that can be used to help improve farm management practices and enhance the productivity and competitiveness of dairy farms. However, to the best of our knowledge, no previous studies have examined the heterogeneous impacts of stocking rate on dairy production.

The objective of this study is, therefore, to analyse the impact of stocking rate on dairy production. Using New Zealand DairyBase® data for the period 2005-2014, we analyse the impact of stocking rate on both milksolids production per hectare and milksolids production per cow.[2] The contributions of this study are twofold. First, unlike previous studies that assume

[2] Globally, milk is usually valued in two ways to reflect a milk component market price: milksolids price (i.e. the globally traded value of fat and protein products) and milk price (i.e. a fluid market milk price where milk composition is not considered). In the context of New Zealand, milksolids price is used in milk transaction markets.

a homogenous relationship across the entire distribution of dairy production, in this study we investigate the heterogeneous effects of stocking rate on milksolids production. Second, a fixed-effects unconditional quantile regression (UQR) model is employed to control for unobserved farm-specific factors that are time invariant. This approach highlights the fact that the distribution of the outcome variable (i.e. milksolids production) can change in ways that are not revealed by an examination of averages.

The rest of the paper is organized as follows. Section 2 presents the data and descriptive statistics. Section 3 introduces the econometric model used in the present study. The empirical results are presented in Section 4, while the final section concludes

2. Data and descriptive statistics

The data used in the present study were from the DairyBase® database, which were collected annually through DairyNZ Economic Survey of dairy farmers.[3] DairyNZ, which represents New Zealand's dairy farmers, is funded by a levy on milksolids and through government investment. The survey was conducted mainly in five regions in the North Island (i.e. Northland, Waikato, Bay of Plenty, Taranaki, and Lower North Island) and three regions in the South Island (i.e. West Coast-Tasman, Marlborough-Canterbury, and Otago-Southland), covering the main dairy production regions in New Zealand. In consideration of the data availability, we use an unbalanced panel for the period 2005-2014 in this study. The final dataset includes 9,218 observations based on 3,040 dairy farms (See Table A1 in the Appendix).

The dependent variable considered in the present study refers to milksolids production, which is measured by both kg/hectare and kg/cow. Stocking rate refers to the number of cows milked per milking hectare (i.e. cows/hectare).[4] The selection of the control variables is based on the existing literature on stocking rate and dairy production (Duguma et al. 2012; Ma et al.

[3] DairyBase® is owned and managed by DairyNZ on behalf of the dairy farmers of New Zealand.

[4] The number of cows is calculated as the highest number of cows used for production during the season.

2018; Macdonald et al. 2011; McCarthy et al. 2010; Patton et al. 2016) and more pragmatically on the data available in DairyBase® (2006). In particular, we include variables representing herd size, farm size, milking interval, dairy breed type, paid labour (measured in full-time equivalent (FTE) where one FTE is equal to 2,400 hours of work a year) , unpaid management, irrigation access, and farm location in the analysis.

Definitions of the selected variables are presented in Table 1, in addition to the descriptive statistics for these variables. It shows that over the 2005 to 2014 period the average milksolids produced within the sampled farms is 1,107 kg/hectare or 370 kg/cow, which ranged from 239 to 3,331 kg/hectare and from 118 to 743 kg/cow, respectively. During the same time period, average herd size was 473 cows, on 160 pasture hectares, which represents a stocking rate of 2.96 cows/ha. The stocking rate in the sample varied between 0.98 and 7.88 cows/hectare. Table 1 also shows that the majority of dairy farms (92%) in the sample chose to milk twice a day, and just around 50% of dairy farms used crossbred cows for milksolids production. On average, 19% of dairy farms had access to irrigation and around 28% of the farms in the sample were located in the South Island.

Figure 1 demonstrates the relationship between stocking rate and milksolids production per hectare over time. It shows that the average stocking rate has increased from 2.92 in 2005 to 2.99 in 2014, while milksolids production has increased from 1,050 kg/hectare to 1,220 kg/hectare during the same time period. The relationship between stocking rate and milksolids production per cow over the period is illustrated in Figure 2. Although there were some fluctuations during the period, average milksolids production per cow also increased from 356 kg in 2005 to 402 kg in 2014

Tables 2 and 3 present information on selected variables by milksolids production per hectare and by milksolids production per cow at the 10th, 30th, 50th, 70th and 90th quantiles, respectively. Table 2 implies that from the lowest 10th quantile of milksolids production per hectare to the highest 90th quantile of milksolids production per hectare, the stocking rate increased from 2.15 cows/hectare to 3.41 cows/hectare. Table 3 shows that with increasing milksolids production per cow from the 10th quantile to the 90th quantile, the corresponding stocking rate has also increased, from 2.71 cows/hectare to 3.16 cows/hectare. The findings tend to suggest that there is a positive linear relationship between stocking rate and milksolids production per hectare. However, it is not possible to conclude that stocking rate increases milksolids production per hectare or milksolids production per cow significantly, because simple descriptive statistics do not control for other factors (e.g., herd size, farm size, labour availability, and farm location) that may also affect milksolids production. Therefore, we employ an econometric approach to estimate the impact of stocking rate on dairy production and provide robust results.

3. Econometric model

To estimate the impact of stocking rate on milksolids production, we start with a simple empirical model of the following form:

$$\ln(Y_{it}) = \beta_0 + \beta_{it}S_{it} + \gamma_{it}\bar{X}_{it} + \varepsilon_{it} \tag{1}$$

where $\ln(Y_{it})$ refers to the log-transformed outcome variable (i.e. milksolids production per hectare or milksolids production per cow) by farm i in year t; S_{it} refers to stocking rate of farm i in year t; $\bar{X}_{it}$ refers to a vector of control variables (e.g., herd size, farm size, milking interval, dairy breed, paid labour, unpaid management, irrigation access and farm location) that are expected to affect milksolids production; β_0 is the constant term; β_{it} and γ_{it} are parameters to be estimated; ε_{it} represents the idiosyncratic error term which is assumed to be independent and identically distributed.

In Equation (1), the effect of stocking rate on milksolids production is captured by β_{it}. Given the nature of panel data, a fixed effects model or a random effects model can usually be used to estimate the homogenous/mean-based effect of stocking rate on milksolids production.[5] However, in the present study, we are more interested in estimating the heterogeneous effects of stocking rate on milksolids production, therefore a quantile regression model is preferred. Conditional quantile regression (CQR) and unconditional quantile regression (UQR) models have both been applied in empirical studies. For example, using a CQR model, Mishra and Moss (2013) analyzed how off-farm income of farm households affects farmland values in the U.S.. Relying on the UQR approach, Maclean et al. (2014) investigated the effect of cigarette tax increases on the number of cigarettes smoked in the past 30 days among a sample of adult smokers, and Khanal et al. (2018) estimated the impact of participation in certified organic food production on farm financial performance.

In the present study, the UQR model developed by Firpo et al. (2009) is adopted, because it is generally confirmed that the UQR model provides more policy-relevant information than the CQR model (Maclean, Webber, and Marti 2014; Powell 2010; Borah and Basu 2013; Khanal, Mishra, and Honey 2018). This is part due to the fact that when compared with the UQR model, the quantiles in the CQR model are defined pre-regression and thus do not change when dropping or adding covariates in the model (Killewald and Bearak 2014).[6]

The UQR approach involves regressing the Recentered Influence Function (RIF) of the unconditional quantile of the dependent variable (i.e. milksolids production) on the explanatory variables. Following Firpo et al. (2009), the RIF of the τ-th quantile of the Y_{it} distribution can be defined as:

$$RIF\left(Y_{it};\ q_\tau, F_{Y_{it}}\right) = q_\tau + \frac{\tau - \mathbb{1}\{Y_{it} \leq q_\tau\}}{f_y(q_\tau)} \tag{2}$$

[5] A fixed effects model assumes that the individual specific effect is correlated to the independent variable, while a random effects model assumes that the individual specific effects are uncorrelated with the independent variables.

[6] The CQR model measures $\frac{\partial Y\ (q^{th}|S,X)}{\partial S}$, while the UQR model measures $\frac{\partial Y\ (q^{th})}{\partial S}$.

where Y_{it} is the outcome variable (i.e. the milksolids production per hectare or per cow); q_τ is the value of the outcome variable at the quantile τ; $F_{Y_{it}}$ is the cumulative distribution function of Y_{it}; $\mathbb{I}\{Y_{it} \leq q_\tau\}$ is a dummy variable which indicates whether the outcome variable is below q_τ; $f_y(q_\tau)$ is the density at the point q_τ (as estimated by Kernel methods). After this transformation, a least squares regression with the RIF as the dependent variable can be undertaken. For example, for the 50th percentile of the distribution, the feasible empirical RIF would be computed as:

$$RIF\left(Y_{it};\ q_{0.50}, F_{Y_{it}}\right) = \hat{q}_{0.50} + \frac{0.50 - \mathbb{I}\{Y_{it} \leq \hat{q}_{0.50}\}}{f_y(\hat{q}_{0.50})} \tag{3}$$

Given our data sample includes 9,218 observations based on 3,040 dairy farms for the period 2005-2014, we need to include fixed effects in the UQR model estimations in order to control for all unobserved farm-specific traits that are time invariant. For this consideration, different strategies have been practiced in previous studies. For example, Killewald and Bearak (2014) used a computationally undemanding approach of demeaning their variables and including the demeaned variables in an ordinary least-squares model. However, this approach generates complications in terms of estimating the standard errors. By contrast, Budig and Hodges (2014) suggested a least-squares dummy variables (LSDV) approach that is less prone to coding errors, however this estimator is very slow when high-dimensional fixed effects are included.

Alternatively, Borgen (2016) extended the work of Firpo et al. (2009) and introduced a two-step approach that allows us to easily include high-dimensional fixed effects in the UQR model. The UQR fixed effects model has been applied in recent studies (e.g., Markowitz et al. 2017; Wang and Lien 2018).[7] In its application to this study, the density is estimated using the Gaussian Kernal and the Silberman optional bandwidth, while standard errors are bootstrapped

[7] The UQR fixed effects model can be implemented by "*xtrifreg*" in STATA.

with 200 replications and clustered on the individual farms. For comparison purposes, we also report the results estimated from a fixed effects model where the mean-based effect of stocking rate on dairy production is estimated.

4. Empirical results

4.1 Modelling the effects of stocking rate on milksolids production per hectare

The estimates for the impact of stocking rate on milksolids production per hectare using the UQR model with fixed effects are presented in Table 4. For the sake of simplicity, we only present the results estimated at the 10th, 30th, 50th, 70th and 90th quantiles. For comparison purposes, we also present the results for the fixed effects model in the last column of Table 4.

Table 4 shows that the impacts of stocking rate are uniformly positively across the UQR, suggesting that an increase in stocking rate is associated with an increase in milksolids production per hectare. The stocking rate's positive impact remains even after controlling for important farm-specific characteristics and unobserved fixed effects. The results show that stocking rate has the largest effect on milksolids production per hectare at the 50th quantile, and an additional increase in stocking rate (i.e. one cow/ha increase) increases milksolids production per hectare by 0.25%. At the lowest 10th quantile and the highest 90th quantile, an additional increase in stocking rate increases milksolids production per hectare by 0.18% and 0.21%, respectively. These findings cannot be observed if we only refer to the descriptive results in Table 4 which show a linearly increasing relationship between stocking rate and milksolids production per hectare across the selected quantiles. The results estimated from the fixed effects model show that an additional increase in stocking rate increases milksolids production by 0.23%. The estimates suggest that using the UQR model with fixed effects is more efficient than using the mean-based fixed effects model estimation. Our findings of the positive relationship between stocking rate and milksolids production per hectare are consistent with previous studies in the literature (Patton, Pierce, and Horan 2016; Macdonald et al. 2008;

Monaghan et al. 2005).

Herd size and farm size affect milksolids production per hectare differently at different quantiles. The results show that for every 100 cows increase in herd size milksolids production per hectare increases by 6.4% at the 10th quantile and 9% at the 90th quantile. However, at the 50th quantile, our results show that every 100 increase in herd size decreases milksolids production per hectare by 3.2%. Our results also show that every 100 hectare increase in farm size decreases milksolids production per hectare by 33% at the 10th quantile and 22% at the 90th quantile, respectively. Note that the fixed effects model estimates show that every 100 increase in herd size increases milksolids production per hectare by 1%, while every 100 hectare increase in farm size decreases milksolids production by 9.2%. The UQR model with fixed effects provides more information by investigating the impact of herd size and farm size on milksolids production.

The labour variables appear to have important impacts on milksolids production per hectare. The coefficients of paid labour are positive and statistically significant at all selected quantiles, suggesting that an additional increase in paid labour increases milksolids production per hectare by 0.04% at the 10th quantile and by 0.03% at the 90th quantile. The unpaid management affects milksolids production significantly only at the 10th and 50th quantiles, increasing milksolids production by 0.04% and 0.03%, respectively.

Following Thornton and Innes (1989), the proportional impact of the discrete variables including milking interval, dairy breed, irrigation and farm location on milksolids production is measured as $p_i = [\exp(\alpha_i) - 1]$, where α_i is the coefficient of the discrete variables. The estimated effect of milking interval on milksolids production per hectare at the lowest quantile is higher than that at the highest quantile. For dairy farms milking twice a day, the increase in milksolids production per hectare at the 10th quantile is 15.26% (exp[0.142]-1) compared with dairy farms using other milking strategies (e.g., once a day or 3 times in 48 hours), while the increase at the 90th quantile is 3.36%. Adoption of crossbred cows increases milksolids production per hectare positively. The results show that for dairy farms adopting crossbreed cows, the milksolids production significantly increases by 5% to 6% at the 30th and 70th quantiles. The finding of a positive relationship between crossbred cow adoption and milksolids production is in line with the argument that crossbreeding improves the health and efficiency of milking cows through: introducing favourable genes from other breeds; removing inbreeding depression; and maintaining the gene interactions that cause heterosis (VanRaden and Sanders 2003; Abdulai and Huffman 2005).

The results show that compared with dairy farms without irrigation, farms with access to irrigation increase per hectare milksolids production by 8.3% at the 30th quantile and by 9.3% at the 50th quantile, respectively. The finding is in line with McDowell (2017) who showed that the irrigation of dryland pastures can markedly improve the level of production from grazing systems. In contrast, the fixed effects model estimates presented in the last column of Table 4 show that, on average, access to irrigation increases milksolids production per hectare by only 3.9%.

Dairy farms located in the South Island tend to have a higher milksolids production relative to their counterparts in the North Island (Table 4). In particular, the significant and statistically positive coefficient of farm location at the 70th quantile column suggests that milksolids production of dairy farms in the South Island is 13.39% higher than that of dairy farms in the North Island. This finding suggests the presence of location-fixed effects that affect milksolids production, which is in line with the argument of Macdonald et al. (2011) who stated that differences between farms in terms of soil fertility, climate, the availability and price of supplements all influence the amount of feed available per hectare, which finally impacts on farm economic performance.

4.2 Modelling the effects of stocking rate on milksolids production per cow

Previous studies have shown that stocking rate increases dairy production per hectare, but decreases dairy production per cow (McCarthy et al. 2010; Macdonald et al. 2008). Therefore we develop our analysis beyond the impacts per hectare and estimate the heterogeneous impacts of stocking rate on milksolids production per cow and present the results in Table 5.

Our estimates show that stocking rate decreases milksolids production per cow, and all the estimated coefficients of stocking rate are negative and statistically significant at the 1% level. In particular, stocking rate has the highest impact on milksolids production per cow at the lowest 10^{th} quantile, decreasing milksolids production by 0.12%. At the 50^{th} and 70^{th} quantiles, an additional increase in stocking rate decreases milksolids production per cow by 0.10% and 0.05%, respectively. Higher stocking rates on pasture-based systems may reduce dairy productivity because individual cow intake of pasture will reduce as stocking rate increases. Macdonald et al. (2008) summarized that shortening lactation length, lower peak, poorer persistency, and lower total amount of feed available per cow are the main determinants of lower milksolids production per cow with increasing stocking rate.

Herd size affects milksolids production per cow significantly only at the 90^{th} quantile, which suggests that every 100 cows increase in herd size increases milksolids production by 2.5%. Farm size tends to have a negative and statistically significant impact on milksolids production per cow at all selected quantiles. For example, our estimates show that every 100 hectare increase in farm size decreases milksolids production per cow by 8.2% at the 10^{th} quantile and by 5.1% at the 70^{th} quantile, respectively.

Paid labour affects milksolids production per cow positively, but the effects are declining with increasing selected quantiles. In particular, we show that an additional increase in paid labour increase milksolids production per cow by 0.12% at the 10^{th} quantile, while it only increases milksolids production per cow by 0.04% at the 70^{th} quantile. With respect to unpaid management, our estimates suggest that an additional increase in unpaid management time increases milksolids production per cow by 0.05% and 0.03% at the 30th and 50th quantiles, respectively. The effect of unpaid management on milksolids production per cow at the 70th quantile is the same with the effect estimated by the fixed effects model, which increases milksolids production per cow by 0.03%.

The impacts of the discrete variables including milking interval, dairy breed, irrigation and farm location on milksolids production per cow are also measured as $p_i = [\exp(\alpha_i) - 1]$, following Thornton and Innes (1989). The estimates show that relative to other milking strategies, milking twice a day increases milksolids production per cow by 2.33 to 3.67% at the selected quantiles. Adoption of crossbreed cows increases milksolids production per cow by 5.34% at the 10th quantile and by 3.05% at the 30th quantile, respectively. Relative to dairy farms located in the North Island, those producing milk in the South Island at the 10th and 70th quantiles can produce 34.31 % and 10.63% more milksolids, respectively.

4.3 Further estimations and discussions

One of the primary objectives of pasture-based dairy producers is to maximize profitability of grazing land through increased pasture production and utilization. Given the findings that stocking rate increases milksolids production per hectare but decreases milksolids production per cow, should we expect that stocking rate affects dairy profitability per hectare positively but dairy profitability per cow negatively? To find an answer to the question, we estimated the impact of stocking rate on dairy profitability per hectare and dairy profitability per cow using the UQR models with fixed effects. For the sake of brevity, we only present in Table 6 the coefficients of stocking rate, while the coefficients of other variables are not included they are available on request.

The results show that stocking rate has a positive impact on dairy profitability per hectare, but all the estimated coefficients are statistically insignificant. In comparison, the fixed effects model results, which are presented in the last column of Table 6, show that an additional increase in stocking rate (i.e. one one/hectare increase) increases dairy profitability by 0.17% on average. In addition, stocking rate appears to have different impacts on dairy profitability per cow, but the impact is only statistically significant and negative at the 90th quantile. The coefficient of stocking rate at the 90th quantile suggests that an additional increase in stocking rate decreases dairy profitability per cow by 0.14%. The findings further confirm that the estimates of the UQR model with fixed effects enable to provide more information regarding the heterogeneous effects of stocking rate on dairy production.

Given that dairy profitability is mainly determined by milksolids production, milk price and production costs, we also estimated the impact of stocking rate on dairy operating expenses per hectare and operating expenses per cow, respectively.[8] The results, which are presented in the lower parts of Table 6, show that stocking rate increases operating expenses significantly. The findings indicate that an additional increase in stocking rate increases operating expenses per hectare by 0.21% at the 10th quantile, 0.24% at the 70th quantile, and 0.33% at the 90th quantile, respectively. The effects of stocking rate on operating expenses per hectare at these three quantiles are higher than the effects of stocking rate on milksolids production per hectare. The findings suggests that although stocking rate increases milksolids production per hectare, it increases operating expenses as well, which finally restricts farmers to benefit from dairy farming through increasing stocking rate. With respect to operating expenses per cow, our UQR fixed effects estimates show that an additional increase in stocking rate decreases operating expenses per cow by 0.17% at the 10th quantile and by 0.08% at the 30th quantile, respectively.

Generally, our estimates show that although increased stocking rate contributes to an increase in milksolids production per hectare, it also brings increased operating expenses per

[8] In New Zealand, dairy farmers are usually price-takers and there exist small variations in milk prices among dairy farms. Thus, milk price is not a main indicator that determines dairy profitability in New Zealand, and this is supported by the findings in Ma et al. (2018).

hectare, resulting in no significant effect of stocking rate on dairy profitability per hectare. For example, increased stocking rate requires additional supplementary feed - an important input determining overall operating expenses (Patton, Pierce, and Horan 2016). In addition, although stocking rate has a negative impact on the operating expenses per cow, the magnitudes of reduction in operating expenses are smaller than the magnitudes of reduction in milksolids production per cow. Though overall this leads to an insignificant impact of stocking rate on dairy profitability per cow. The findings are quite similar to the findings of Ma et al. (2018) who found that intensifying dairy production in New Zealand does increase dairy productivity but does not increase profitability, because increased production costs due to intensification cannot be compensated for by increased gross revenue.

5. Conclusions

This paper contributed to the literature by exploring the heterogeneous effects of stocking rate on milksolids production per hectare and milksolids production per cow, using New Zealand dairy farm business data for the period 2005-2014 provided by DairyBase®. We employed an UQR model with fixed effects to control for unobserved farm-specific traits that are time invariant.

Our estimates showed that an additional increase in stocking rate (i.e. one cow/ha increase) increases milksolids production per hectare by between 0.18 and 0.25%, with the highest effect occurring at the 50^{th} quantile. Stocking rate decreased milksolids production per cow by between 0.05 and 0.12%, with the highest impact occurring at the 10^{th} quantile. With respect to other factors that affect milksolids production, we found that paid labour, unpaid management, milking interval, dairy breed, irrigation access, and farm location increase both milksolids production per hectare and milksolids production per cow.

The further analyses revealed that stocking rate does not increase dairy profitability per hectare and dairy profitability per cow significantly. The results showed that an additional increase in stocking rate increases operating expenses per hectare by between 0.18 and 0.33% at the selected quantiles. Stocking rate had a significant impact on the operating expenses per cow only at the 10th and 30th quantiles, decreasing the operating expenses per cow by 0.17% and 0.08%, respectively. However, the magnitudes of operating expenses reduction due to increased stocking rate are still smaller than that of milksolids production per cow reduction. These findings showed that increasing stocking rate also involves increased operating expenses, which reduces dairy farmers' profits.

Our findings suggest that appropriate dairy farm management should consider the optimal stocking rate in their efforts to enhance farm economic performance through increasing stocking rate. The finding of the positive relationship between crossbred cow adoption and milksolids production suggests that promoting crossbred-cow adoption amongst dairy farmers could give a boost to the development of dairy industry. The finding that access to irrigation increases milksolids production highlights the importance of developing irrigation infrastructure to further improve the results of dairy farmers, by raising their milksolids output.

Although we provide important insights as to the heterogeneous relationship between stocking rate and dairy production, it should be noted that stocking rate (i.e. cows/hectare) used in this study does not take into account the mass and weight of cows and the quantity of dry matter available per hectare due to the absence of required data. This suggests that when the required data are available, it could be a promising area for future work to investigate how comparative stocking rate (i.e. kilograms of body weight per tonne of feed available) affects dairy production. In comparison to stocking rate as defined in this study, the comparative stocking rate suggested in Macdonald et al. (2008) accounts for known or modeled variations in pasture production, the inclusion of supplementary feeds, and cow body weight (a proxy for genetic merit for milk production).

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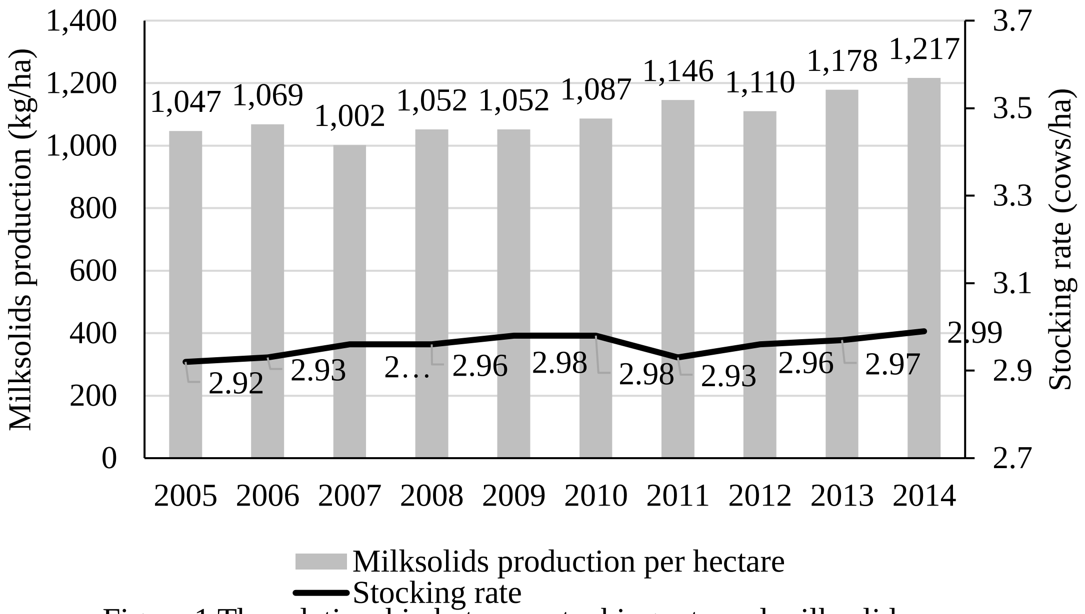

Figure 1 The relationship between stocking rate and milksolids production per hectare over time (2005-20014)

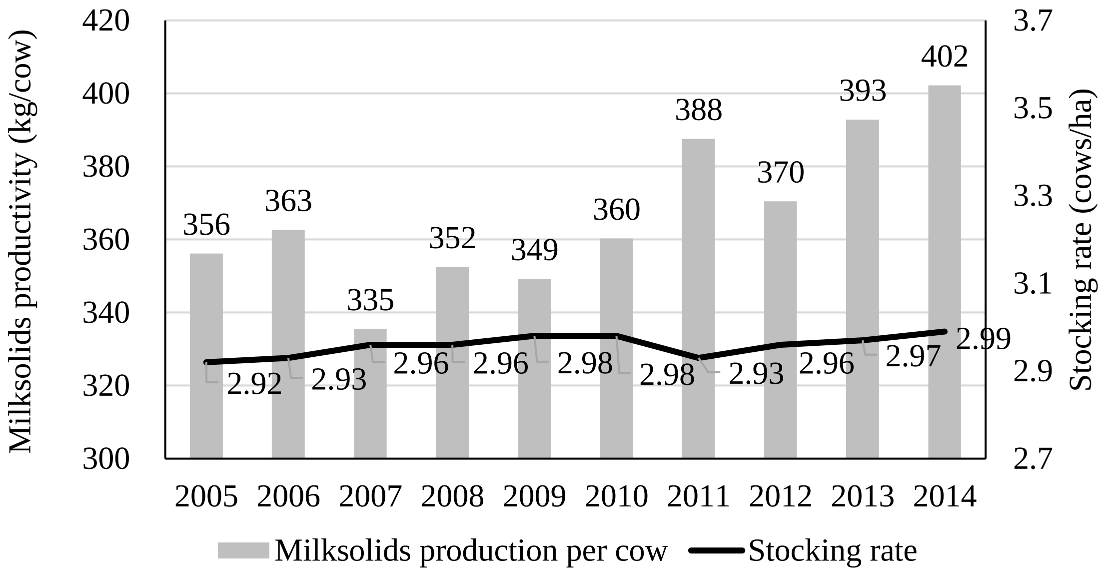

Figure 2 The relationship between stocking rate and milksolids production per cow over time (2005-20014)

Table 1 Definition and descriptive statistics of the selected variables

Variables	Definition	Mean	Min.	Max.
Milksolids per hectare	Milksolids production (kg/hectare)	1,107	239	3,331
Milksolids per cow	Milksolids production (kg/cow)	370	118	743
Stocking rate	Average number of peak cows milked per milking hectare	2.96	0.98	7.88
Herd size	The highest number of cows milked (herds)	473	55	8,650
Farm size	The total pasture area for milking cows (hectares)	160	25	2,280
Milking interval	1=milking twice a day, 0=others	0.92	0	1
Dairy breed	1=Crossbred, 0=others	0.50	0	1
Paid labour	Full time equivalents (FTE) paid labour [a]	2.05	0	51.28
Unpaid management	The full time equivalent (FTE) of all unpaid (usually family) farm management.	0.76	0	1
Irrigation	1 if dairy farm has access to irrigation, 0 otherwise	0.19	0	1
Farm location	1 If farm is located in South Island; 0=otherwise	0.28	0	1
Profitability per hectare	The operating profit of dairy production (NZ$/hectare)	2,060	0.63	9,794
Profitability per cow	The operating profit of dairy production (NZ$/cow)	688	0.30	2,470
Operating expenses per hectare	The operating expense of dairy production (NZ$/hectare)	4,672	818	19,522
Operating expenses per cow	The operating expense of dairy production (NZ$/cow)	1,568	411	5,827

Note: More detailed definitions of the variables are available in DairyBase® (2006).
[a] 1 FTE= 2,400 hours

Table 2 Farm-level characteristics by milksolids production per hectare quantiles during the period sampled (2005-2014)

Variables	Selected quantiles					Total
	10th	30th	50th	70th	90th	
Stocking rate (cows/ha)	2.14	2.68	2.92	3.09	3.41	2.96
Herd size (cows)	378	395	438	451	603	473
Farm size (ha)	177	149	152	147	176	160
Milking interval (dummy)	0.77	0.90	0.93	0.94	0.98	0.92
Dairy breed (dummy)	0.47	0.45	0.50	0.48	0.53	0.50
Paid labour [a]	1.47	1.60	1.83	1.92	2.84	2.05
Unpaid management [b]	0.81	0.80	0.785	0.79	0.70	0.76
Irrigation (dummy)	0.04	0.07	0.11	0.17	0.44	0.19
Farm location (dummy)	0.17	0.15	0.20	0.25	0.48	0.28

[a] and [b]: Paid labour and unpaid management are measured by full time equivalents (FTE, and 1 FTE= 2,400 hours) (DairyBase®, 2006).

Table 3 Farm-level characteristics by milksolids production per cow quantiles during the period sampled (2005-2014)

Variables	Selected quantiles					Total
	10th	30th	50th	70th	90th	
Stocking rate (cows/ha)	2.71	2.86	2.91	3.02	3.16	2.96
Herd size (cows)	407	407	433	490	584	473
Farm size (ha)	154	146	151	162	182	160
Milking interval (dummy)	0.76	0.88	0.94	0.97	0.97	0.92
Dairy breed (dummy)	0.46	0.49	0.50	0.51	0.53	0.50
Paid labour [a]	1.53	1.62	1.84	2.23	2.78	2.05
Unpaid management [b]	0.75	0.76	0.78	0.74	0.73	0.76
Irrigation (dummy)	0.05	0.08	0.15	0.24	0.39	0.19
Farm location (dummy)	0.09	0.12	0.25	0.35	0.49	0.28

[a] and [b]: Paid labour and unpaid management are measured by full time equivalents (FTE, and 1 FTE= 2,400 hours) (DairyBase®, 2006).

Table 4 Impact of stocking rate on milksolids production per hectare: UQR and fixed-effects OLS estimations

Variables	UQR with fixed effects 10th	30th	50th	70th	90th	Mean [c]
Stocking rate (cows/ha)	0.18	0.23	0.25	0.22	0.21	0.23
	(0.06)***	(0.03)***	(0.03)***	(0.03)***	(0.05)***	(0.02)***
Herd size (100 cows)	0.06	-0.00	-0.03	-0.02	0.09	0.01
	(0.03)**	(0.01)	(0.01)***	(0.01)	(0.03)***	(0.01)*
Farm size (100 ha)	-0.33	-0.07	0.03	-0.00	-0.22	-0.09
	(0.10)***	(0.05)	(0.03)	(0.04)	(0.07)***	(0.02)***
Milking interval (dummy)	0.04	0.03	0.03	0.04	0.03	0.03
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.00)***
Dairy breed (dummy)	0.04	0.03	0.03	0.02	0.01	0.03
	(0.02)*	(0.02)	(0.01)**	(0.02)	(0.02)	(0.01)***
Paid labour [a]	0.14	0.08	0.04	0.05	0.03	0.07
	(0.04)***	(0.02)***	(0.02)**	(0.02)***	(0.01)***	(0.01)***
Unpaid management [b]	0.00	0.06	0.03	0.05	0.01	0.03
	(0.02)	(0.02)***	(0.01)***	(0.01)***	(0.02)	(0.01)***
Irrigation (dummy)	0.02	0.08	0.09	0.09	-0.04	0.04
	(0.06)	(0.04)**	(0.03)***	(0.04)**	(0.04)	(0.02)***
Farm location (dummy)	0.35	0.17	0.12	0.17	-0.02	0.19
	(0.22)	(0.12)	(0.09)	(0.08)**	(0.10)	(0.07)***
Constant	5.96	6.02	6.16	6.31	6.57	6.16
	(0.21)***	(0.11)***	(0.09)***	(0.09)***	(0.16)***	(0.05)***
R-square (within)	0.06	0.06	0.06	0.06	0.08	0.30
F (8, 6170)	43.52	45.68	43.60	44.29	59.21	
Prob>F	0.00	0.00	0.00	0.00	0.00	
Observations	9,218	9,218	9,218	9,218	9,218	9,218
Groups	3,040	3,040	3,040	3,040	3,040	3,040

UQR: unconditional quantile regression; OLS: ordinary least square;
The dependent variable is the log form of milksolids production measured in kg/ha.
Bootstrapped standard errors are in parenthesis; * p<0.1; ** p<0.05; *** p<0.01
[a] and [b]: Paid labour and unpaid management are measured by full time equivalents (FTE, and 1 FTE= 2,400 hours) (DairyBase®, 2006).
[c] The mean-based effects of stocking rate on milksolids production per hectare are estimated using a fixed effects model for panel data.

Table 5 Impact of stocking rate on milksolids production per cow: UQR and fixed-effects OLS estimations

	UQR with fixed effects					
Variables	10th	30th	50th	70th	90th	Mean [c]
Stocking rate	-0.12	-0.09	-0.10	-0.05	-0.11	-0.09
(cows/ha)	(0.04)***	(0.02)***	(0.021)***	(0.02)***	(0.02)***	(0.01)***
Herd size (100 cows)	-0.01	0.01	0.01	0.00	0.03	0.01
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)***	(0.01)
Farm size (100 ha)	-0.08	-0.08	-0.08	-0.05	-0.09	-0.07
	(0.04)**	(0.03)***	(0.03)***	(0.03)*	(0.04)***	(0.02)***
Milking interval	0.12	0.09	0.06	0.04	0.02	0.07
(dummy)	(0.03)***	(0.02)***	(0.01)***	(0.01)***	(0.02)	(0.01)***
Dairy breed (dummy)	0.02	0.05	0.03	0.03	0.01	0.03
	(0.02)	(0.01)***	(0.01)***	(0.01)***	(0.01)	(0.01)***
Paid labour [a]	0.04	0.03	0.03	0.03	0.02	0.03
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
Unpaid management [b]	0.05	0.03	0.01	0.01	0.02	0.03
	(0.02)**	(0.01)***	(0.01)	(0.01)	(0.01)	(0.01)***
Irrigation (dummy)	-0.02	0.02	0.05	0.06	-0.01	0.04
	(0.03)	(0.03)	(0.02)**	(0.02)***	(0.03)	(0.01)***
Farm location	0.30	0.20	0.22	0.10	-0.03	0.18
(dummy)	(0.14)**	(0.07)***	(0.05)***	(0.05)**	(0.03)	(0.05)***
Constant	5.874	5.93	6.05	6.06	6.39	6.04
	(0.13)***	(0.07)***	(0.07)***	(0.06)***	(0.08)***	(0.04)***
R-square (within)	0.02	0.03	0.03	0.02	0.011	0.07
F (8, 6170)	14.68	19.08	18.81	14.49	7.56	
Prob>F	0.00	0.00	0.00	0.00	0.00	
Observations	9,218	9,218	9,218	9,218	9,218	9,218
Groups	3,040	3,040	3,040	3,040	3,040	3,040

UQR: unconditional quantile regression; OLS: ordinary least square;
The dependent variable is the log form of milksolids production measured in kg/cow;
Bootstrapped standard errors are in parenthesis; * p<0.1; ** p<0.05; *** p<0.01;
[a] and [b]: Paid labour and unpaid management are measured by full time equivalents (FTE, and 1 FTE= 2,400 hours) (DairyBase®, 2006).
[c] The mean-based effects of stocking rate on milksolids production per cow are estimated using a fixed effects model for panel data.

Table 6 Impact of stocking rate on dairy profitability per hectare, dairy profitability per cow, operating expenses per hectare, and operating expensed per cow: UQR and fixed-effects OLS estimations

	UQR with fixed effects					
Variables	10th	30th	50th	70th	90th	Mean[a]
			Dairy profitability (NZ$/ha)			
Stocking rate (cows/ha)	0.03	0.16	0.06	0.14	0.15	0.17
	(0.28)	(0.15)	(0.11)	(0.09)	(0.10)	(0.09)*
			Dairy profitability (NZ$/cow)			
Stocking rate (cows/ha)	0.07	0.02	-0.03	-0.11	-0.14	-0.04
	(0.24)	(0.15)	(0.09)	(0.09)	(0.08)*	(0.09)
			Operating expenses (NZ$/ha)			
Stocking rate (cows/ha)	0.21	0.18	0.25	0.24	0.33	0.24
	(0.07)***	(0.05)***	(0.04)***	(0.05)***	(0.08)***	(0.03)***
			Operating expenses (NZ$/cow)			
Stocking rate (cows/ha)	-0.17	-0.08	-0.07	-0.04	-0.06	-0.09
	(0.07)**	(0.04)**	(0.04)	(0.03)	(0.05)	(0.03)***

UQR: unconditional quantile regression; OLS: ordinary least square;
The dependent variables are the log forms of dairy profitability and operating expenses measured in NZ$/ha and NZ$/cow, respectively.
Bootstrapped standard errors are in parenthesis; * $p<0.1$; ** $p<0.05$; *** $p<0.01$
[a] The mean-based effects are estimated using a fixed effects model for panel data.

Appendix

Table A1 The distributions of sample farms from 2005 to 2014

year	Frequency	Percent	Cum.
2005	556	6.03	6.03
2006	778	8.44	14.47
2007	849	9.21	23.68
2008	586	6.36	30.04
2009	822	8.92	38.96
2010	1,027	11.14	50.10
2011	1,099	11.92	62.02
2012	1,200	13.02	75.04
2013	1,213	13.16	88.20
2014	1,088	11.80	100
Total observations	9,218	100	

Note: The total 9,218 observations are based on 3,040 dairy farms for the period 2005-2014.